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The PRINCIPLES OF THE LIMING OF SOILS

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THE APPLICATION of lime to soils brings about beneficial results in several ways. It stimulates the proper decomposition of the organic matter in the soil, neutralizes acids in the soil, improves the physical condition of heavy soils, supplies lime to growing plants, or makes available other elements in the soil.

The great majority of the soils of the East, South, and portions of the Central West are deficient in lime and will respond in increased yields to applications of lime.

In the following pages information is presented regarding the materials used in liming, their preparation and use, as well as a discussion of the chemical changes brought about in the soil by lime, so far as they are known. The relative merits of different forms of lime are discussed and data furnished whereby the value of any particular form of lime for agricultural purposes may be determined approximately.

The bulletin has been prepared primarily from the point of view of materials used in liming and of the principles involved in their use.

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THE PRINCIPLES OF THE LIMING OF SOILS

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INTRODUCTION

The practice of applying lime to soils to increase the yields of crops has been more or less common in the Eastern States since the first settlement of this country and has been followed in many parts of Europe for centuries.

The term " liming " as used in farming operations means the application to the soil of the element known to chemists as calcium either in the form of the oxide or the carbonate.

Calcium oxide is ordinary burnt lime and is commonly referred to as oxide of lime. Calcium carbonate is the principal ingredient of limestone and is usually spoken of as carbonate of lime. Carbonate of magnesium mixed with carbonate of lime, in magnesium limestone, and the mixed oxides resulting from burning this are included under the term " lime."

These two terms, " oxide of lime " and " carbonate of lime " are inaccurate and would have no place in a strictly scientific discussion, but they are so generally used by dealers and farmers that it has been thought desirable to use them in this bulletin in place of calcium oxide and calcium carbonate. In cases where the element calcium is discussed without reference to any particular form or combination, the term " calcium " is used.

MATERIALS USED IN LIMING

CARBONATE OF LIME

Carbonate of lime occurs in nature in several forms. Limestone and marl are the most common. Marble, chalk, coral, and oyster

and clam shells are forms not so widely distributed. All of these when properly prepared are suitable for agricultural use.

LIMESTONE

Limestone is one of the most common rocks, and its appearance is familiar to many. However, other rocks may be so similar in appearance that they are sometimes mistaken for it. It may vary in color from a very light gray to almost black, with shades of red or brown, and may vary considerably in hardness. It may be distinguished from other rocks of similar appearance by the fact that it effervesces, or gives off bubbles of gas, when a drop of dilute acid is applied to it.

FIG. 1.—Lime spreader in operation

Limestone is prepared for direct agricultural use by grinding or pulverizing and is then marketed as ground or pulverized limestone. (Fig. 2.) It varies in its content of carbonate of lime from 95 per cent or more to less than 80 per cent, and occasionally as low as 60 per cent. The impurities usually present are small quantities of a number of minerals none of which are of any agricultural value, and are so much inert material that must be hauled and handled when a limestone of low grade is used. Except on land in the immediate vicinity of the supply, limestone containing less than 80 per cent of carbonate of lime is not commonly used.

MAGNESIAN LIMESTONE

The term "magnesian" is applied to limestone that contains both carbonate of lime and carbonate of magnesia. The term "dolomitic limestone" is also applied to the same material. In appearance it

often can not be distinguished from ordinary limestone. Usually it does not effervesce on the application of dilute acid at ordinary temperature, but does so on warming. The value of this limestone for agricultural use is considered equal to that of ordinary limestone.

MARL

Marl is a form of carbonate of lime that has been deposited from water, occurring frequently as a deposit under other material or in the beds of streams and in shallow lakes. It usually exists in a more or less finely divided condition, but sometimes the material has become more or less cemented and requires grinding before using. It is more variable in its content of carbonate of lime than is lime-

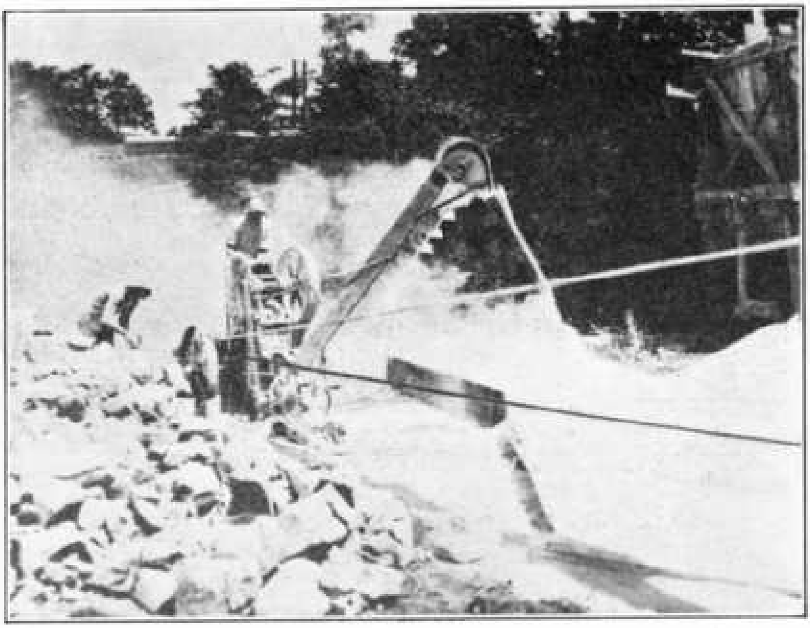

FIG. 2.—Limestone crusher in operation

stone, and the impurities are usually clay or silty material. In some sections, as in New Jersey, the term "marl" is applied to greensand which contains glauconite, a potash mineral. The content of carbonate of lime in greensand usually is low. In some localities deposits of shells partially disintegrated and more or less cemented together are found. Such materials, often known as marl, usually require grinding before they are suitable for agricultural use.

MARBLE

Marble has the same chemical composition as high-grade or pure limestone. It is too valuable for other purposes to be used in agriculture, but sometimes small quantities of marble waste are available for this purpose.

CORAL

Coral is the skeleton remains of marine organisms and is chiefly carbonate of lime. Where coral deposits have become elevated above sea level, the material where exposed may become soft and friable, much like marl in character; below the surface, however, it is usually hard and must be ground before it can be used. Coral deposits are of limited extent in the United States, being confined to parts of Florida. As an agricultural lime, coral may be considered of the same value as limestone or marl of the same content of carbonate of lime.

OYSTER AND CLAM SHELLS

Oyster and claim shells when cleaned of adhering dirt and organic material, contain from 90 to 95 per cent of carbonate of lime. When coarsely ground they are much used as mineral matter for poultry. In the preparation of this poultry feed the finer material is sometimes sifted out and offered for agricultural use. Such material may contain all the sand and dirt that accompanied the shells. Clean shells when burned or when finely ground constitute a very valuable, although limited, supply of lime for agricultural purposes and have the same agricultural value as other forms having the same content of lime.

CHALK

Chalk is material that has been deposited in much the same way that marl has been and is very free from impurities. It has been extensively used in agriculture in some countries, but deposits in this country are not of sufficient extent to furnish much material for liming. Deposits in this country that are known as chalk should probably more properly be called marl.

WASTE LIME

In many industries there are waste products which contain oxide of lime or lime carbonate, that often can be obtained and used locally at small cost. Such products are the lime from gas works, paper mills, beet-sugar mills, tanneries, water-softening processes, spent calcium carbide, and slags from iron or other works. As these substances may contain compounds injurious to vegetation their freedom from such should be assured before they are used. They also usually contain excess of moisture and can not be shipped profitably without previous drying.

OXIDE OF LIME

Oxide of lime (burnt lime or lump lime) is marketed in several forms, all of which are derived from some form of carbonate of lime by heating or burning. By this process, carbonic acid gas is driven off, and the oxide left. Any of the forms of carbonate mentioned can be used for the manufacture of the oxide; but except for a small quantity obtained by burning oyster shells, all oxide of lime is made from limestone.

BURNED LIME

The term "burned lime" is applied to the ordinary lime that has been prepared by burning limestone. The terms "quicklime," "caustic lime," and "builder's lime" are also applied to this material. In burning, the limestone retains the lump form in which it was placed in the kiln, and the product is marketed as lump lime in bulk or in barrels.

GROUND LIME

The term "ground lime" is applied to burned lime that has been finely ground but has had no other treatment.

HYDRATED LIME

When oxide of lime is treated with water, chemical reaction takes place; heat is generated, and the lump falls to a powder. This process is called "slaking," and the product is known as slaked lime, calcium hydroxide, lime hydroxide, or hydrated lime. The term "Hydrated lime" is the accepted trade name for slaked lime prepared by lime manufacturers. The product is finely divided and is of high grade, because in the process all unburned lumps (core) and slag or overburned lumps are rejected.

AGRICULTURAL LIME

The term "agricultural lime" was originally applied to burned lime from which the unburned lumps or core and overburned lumps had not been taken out, as must be done when burned lime is offered to the building trades or chemical industries. This lime is frequently known as "run-of-kiln" lime. Recently there has been a tendency to apply the term "agricultural lime" to any form of lime used for agricultural purposes, so that at present the term has no special significance.

LIME IN SOILS

All plants need the element calcium to build up their tissues. All soils contain some calcium, and it has been generally assumed that soils contain enough for plant growth. Calcium occurs in soils in a number of different forms. In addition to the carbonate, soils may contain calcium in the form of sulphate (gypsum), or as some of the complex compounds known as silicates. These silicates make up a large part of the rocks from which soils are formed, they are very slightly soluble, and they furnish calcium to the soil solution by slow decomposition. Calcium also occurs in many soils combined with the organic constituents known as humus. In this form it is usually slightly soluble.

Carbonate of lime is much more soluble in the soil water than are the silicates and, when present, it is leached from the soil first and lost in the drainage water. The soils of the Eastern, Southern, and parts of the Central States contain only traces of carbonate of lime; and on the basis of the content of carbonate of lime in the soils, the United States may be divided roughly into two geographic divisions.

If a line, beginning at the center of the northern boundary of Minnesota, be drawn south through that State, curving west and cutting off the northwest corner of Iowa, thence to central Nebraska, south through Kansas, Oklahoma, and Texas, to near the Mexican border on the Gulf, it may be said that, generally, the soils east of this line, except in river bottoms and a few inextensive upland areas, contain but small quantities (less than half of 1 per cent) of carbonate of lime. Such soils do not effervesce on the addition of dilute acid. West of this line the soils frequently, and the subsoils always, contain appreciable quantities of carbonate of lime, except at high elevations and on the Pacific coast.

EFFECTS OF LIMING

If soils generally contain sufficient calcium for the growth of crops, the question naturally arises, Why apply lime? The answer

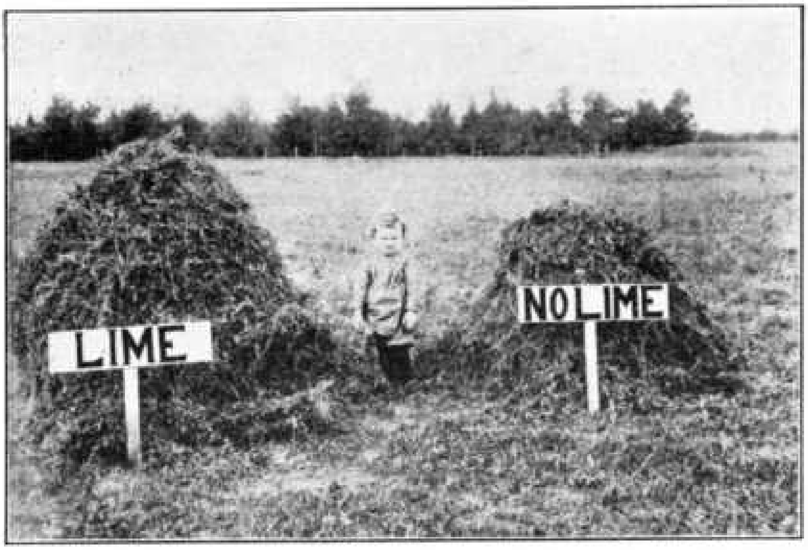

FIG. 3.—Limed and unlimed alfalfa

is that lime in the form either of carbonate or oxide brings about changes in soils that make them more suitable for the growth of some crops. Liming does more than supply calcium to plants.

LIMING CORRECTS SOIL ACIDITY

All soils contain some organic matter, the remains of plants, previous crops, or similar materials that have been added to them. This organic matter decays in the soil, and in this decay organic acids are formed. These acids may combine with the mineral constituents of the soils (their acid natures being thereby neutralized) or they may be prevented from accumulating to an injurious extent by drainage or by changes promoted by free access of air. When this neutralization or change does not take place and acids accumulate, the soil becomes acid, or sour. In cases where soils are acid because

of the presence of organic acids, the soils contain excess of organic material, as is the case in mucks or peats, or in soils containing little organic matter, where there is poor drainage. However, soils that are acid because of the presence of organic acids are not very common.

Many soils contain compounds of an acid nature derived from complex silicates that form a large part of the rocks from which soils are formed. These compounds use up lime in the same way that ordinary acids do; that is, they require the addition of lime before a neutral or alkaline reaction is brought about.

Both the forms of lime used in liming have the power to neutralize acids. Oxide of lime combines directly with the acid, thereby forming a neutral compound; and carbonate of lime enters into a reaction with the acid, whereby carbonic-acid gas is liberated and the same neutral compound formed.

The term "lime requirement" is used to express the quantity of lime that must be added to a soil to cause its acid character to disappear. This is usually stated in pounds of lime oxide or carbonate of lime required for an acre of soil to a depth of 6 inches or some other stated depth.

LIMING IMPROVES THE PHYSICAL CONDITION OF HEAVY, COMPACTED SOILS

In heavy soils which contain large proportions of clay or silt, under certain conditions, the fine soil particles become associated so closely that free access of air and water is prevented, a condition unfavorable to plant growth. Under other conditions the fine particles tend to gather in small groups or floccules, each group behaving as a large particle. The soil particles are then said to have flocculated, and the soil has a crumb structure. Farmers know this crumbly condition of the soil when they see it, and they know that in tilling such soils it is desirable to bring about this condition.

Liming has been found to favor the flocculation of heavy soils, so that the better aeration and drainage which result from the liming of heavy, compacted soils are among the important effects of liming. Lime in the form of oxide is much more effective in bringing this about than is the carbonate form.

LIMING STIMULATES THE PROPER DECOMPOSITION OF ORGANIC MATTER IN SOILS

One of the advantages of an adequate supply of organic matter in a soil, or of supplying this material by means of manure, fertilizers, or cover crops, is that in decomposing it furnishes the food necessary for the growth of the bacteria that render nitrogen in the soil available to plants. It is largely through the decomposition of organic matter in the soil that crops can grow. A soil without organic matter or with organic matter that can not decompose is worth little for crop production.

Lime in the form of oxide or carbonate not only stimulates the decomposition of organic matter in the soil but brings about conditions favorable to a decomposition that is most beneficial to growing crops.

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LIMING MAY INCREASE THE AVAILABILITY OF OTHER MINERALS IN THE SOIL

It has been somewhat generally assumed that one of the beneficial effects resulting from liming is the effect of the lime in rendering other minerals, especially those containing potash, soluble and available to the growing crop. This effect, though it may be somewhat general, is not the same for all soils, and in some soils it is very slight.

LIMING MAY FURNISH NEEDED CALCIUM TO PLANTS

The assumption is general that soils contain sufficient calcium to satisfy the needs of a plant in building up its tissues. This, however, may not always be the case, so that some of the beneficial results from liming may be the direct furnishing of needed calcium to the plant.

FIG. 4.—Results of liming alfalfa

There are soils in which the content of lime in any form is less than the content of any other common element. Thus in growing on such soils crops such as clover or alfalfa (figs. 4 and 5) that require large quantities of calcium, the benefits from liming may be due, in part at least, to the direct supply of calcium.

GENERAL DISCUSSION OF THE EFFECTS OF LIMING

Of the several effects of liming mentioned, the correction of soil acidity is probably most commonly thought or spoken of. This, however, may not be the most important effect. Although there are large areas of uncultivated soil that are decidedly acid, soils that are strongly acid are not nearly so common in cultivation as is generally supposed. Peat and muck soils, where not associated with marl

deposits, are often decidedly acid, and soils of all textures may sometimes be very acid, but the great majority of cultivated soils that are almost devoid of carbonate of lime and that respond to liming are not strongly acid.

It has been stated that decomposed organic matter is essential to a fertile soil, and that organic matter is added to soils in the form of manure, fertilizers, and cover crops for the purpose of being decomposed. The addition of lime influences this decomposition in such a way that the resulting products are favorable to the growth of crop plants. This takes place in all soils, and it would seem that since this effect of liming is the most general, it is the most important.

The effect of liming on the physical condition of the soil is observable where the physical condition is in need of improvement. This will be observed principally on heavy soils.

The effect of lime in liberating other minerals in the soil and of supplying needed lime to the plant are effects that apparently are limited also in their operations to certain types of soil.

It is evident that several or all of the effects of liming may operate in the same soil at the same time, and it is likely that in a few soils the benefits resulting from liming are the results of one effect only.

FARM PRACTICE OF LIMING

In attempting to increase his crop yields by liming, the farmer seeks to accomplish this with the least expense for labor and materials; and he should also keep in mind the desirability of maintaining or increasing the fertility of his soil for future crops.

The factors to be considered in the practice of liming may be discussed under several heads.

THE SOIL

All soils that need lime do not need it for the same reason. As the result of liming, one soil may be benefited chiefly through the neutralization of its acidity and another through the improvement of its physical condition, but in nearly all the decomposition of the organic matter will be favorably influenced, and in some cases all effects will operate at the same time.

The kind of soil and the results to be accomplished will determine in part the practice to be followed. Peats, muck soils, and nearly all soils devoid of carbonate of lime and having poor drainage are likely to be decidedly acid, and the liming of these should be practiced with a view to neutralizing this acidity. This frequently will call for a large application of lime.

A heavy soil that has become compacted so that drainage and circulation of air are hindered should be limed to improve the physical condition, and for that purpose comparatively smaller applications will be effective if the soil is not acid. It may be that the topsoil is in fairly good physical condition but that the drainage is poor because of the presence of a hardpan or impervious layer below the surface. Surface applications of lime may remedy such conditions very slowly, if at all. In some such cases, merely breaking the impervious layer may be sufficient to remedy the condition, but in others, drainage must be provided by the usual means of ditching or tiling.

It is likely that even small applications of lime will stimulate the decomposition of organic matter in a soil. This organic matter is of service because it decomposes, but to hasten its decomposition in a sandy soil which contains little organic matter is sure to be disastrous to future crops. For this reason lime in any form should not be applied to soils that are deficient in organic matter, especially in warm humid climates, without making provision to put organic matter in the form of manure or cover crops into the soil to keep up, and if possible increase, the supply of this necessary constituent.

THE CROP

In considering the crop in its relation to liming, it seems that, except for some special crops, the nature of the soil will determine whether a particular crop requires that lime should be added to the soil for best production.

Of first consideration in this connection is the fact that leguminous plants usually require a plentiful supply of calcium—that is, the common legumes take large quantities of calcium from the soil. Further, many legumes are sensitive to acid-soil conditions and do not grow well or frequently not at all where such acid conditions exist. This is particularly true of alfalfa and red clover and perhaps to a less degree of sweet clover and vetch. On the other hand, cowpeas and soy beans usually do not respond to liming, and white clover grows well on acid soils.

Corn is usually considered to be tolerant of acid conditions, and such grasses as redtop, Bermuda grass, and Lespedeza grow well on acid soils. Bog plants, such as blueberries and cranberries, require an acid soil, and such fruits as strawberries and raspberries apparently are not benefited by applications of lime.

The great majority of garden and truck crops and cereals usually are benefited by liming, but when it is recognized that different soils may require lime for different reasons, it is clear that a crop that responds to liming on one soil may not do so on another. For this reason it is very desirable that farmers should experiment with their own soils to determine the response to liming with different crops.

USE OF LIMING MATERIALS

The material used in liming is either carbonate of lime, oxide of lime, or the hydrated form, and of these there are several forms of each. It sometimes happens that because of local conditions, a farmer is limited to one form of lime, but usually he has a choice of several kinds or brands.

CARBONATE OF LIME

Carbonate of lime is almost insoluble in water, but soil moisture holding carbonic-acid gas in solution dissolves appreciable quantities. It is because of this solubility that carbonate of lime is gradually leached from soils. In most cases the neutralization of soil acid is probably brought about by the carbonate of lime in solution coming in contact with the acid.

The action of carbonate of lime in stimulating the decomposition of organic matter is not thoroughly understood. It is known, however,

that the growth of many microorganisms is greatly influenced by the presence of acid, so that the stimulation of the decomposition of organic matter in a soil may be the indirect effect of the neutralization of the acid. In other cases the favorable action may be the result of the formation of new compounds (formed by the combination of lime with neutral organic matter) which become available for plants or microorganisms.

The effects of lime in flocculating soil particles and making the conditions more favorable for the circulation of air and water, as well as the effect of making soluble other minerals, so far as they are understood, depend on the lime being in solution in the soil moisture.

It is seen then that the beneficial effects of carbonate of lime when added to a soil follow only after this lime has gone into solution. This being true, the value of any carbonate of lime, so far as its chemical activity in the soil is concerned, depends on its content of carbonate and on its solubility.

The rapidity with which any material not readily soluble in water is dissolved depends on how finely it is powdered; and for all practical purposes, the rate of solution of one kind of carbonate of lime may be assumed to be the same as that of any other kind of the same degree of fineness.

In addition to its effect on rate of solution, fineness of grinding makes it possible for the material to be more thoroughly distributed throughout the soil in a shorter time.

The value of carbonate of lime, therefore, so far as its immediate activity in the soil is concerned, is dependent on the fineness of pulverization.

OXIDE OF LIME

It has been pointed out that any form of carbonate furnishes lime oxide on burning. When calcium oxide or oxide of lime is brought in contact with water, chemical action takes place, heat is generated, and the lump of lime falls to a dry powder or forms a semifluid milky mass, according to the quantity of water used.

In this reaction (slaking) chemical combination between the oxide and water takes place. The same action takes place more slowly when the oxide is exposed to the air. In this exposure the moisture of the air is taken up by the lime, but the process is extended over so long a period of time that the heat generated is not noticeable. This process, called air-slaking, takes place even in fairly tight containers, such as barrels. The oxide of lime after slaking, is known as calcium hydroxide, or lime hydroxide; and usually when lump lime, or oxide of lime, is used in agriculture, it is slaked and changed to the hydroxide form before it is used.

Lime hydroxide is much more soluble than is carbonate of lime, either in water or in soil moisture containing carbonic acid. When lime hydroxide is applied to a moist soil, solution takes place, and this lime in solution tends to be diffused throughout the soil. At the same time it may be converted into calcium carbonate through interaction with the carbonic acid also held in solution. The extent to which this reaction goes depends on the proportions of the two reacting compounds present. If much calcium carbonate is formed

in this way, it would be thrown out of solution and finally react in the soil in the same way as finely divided carbonate added to the soil directly.

In some cases, no doubt, there is direct union of the lime hydroxide with organic compounds without the previous formation of carbonate; but in a general way, the chemical processes by which beneficial effects on crops are produced must be the same whether the oxide or carbonate be used.

If the oxide is applied to the soil without first slaking it, contact with moist soil will cause the material to slake. In this process considerable heat is generated, and chemical changes may be brought about in the soil at the points where the slaking takes place that are very different from those which result from the applications of slaked lime. It is principally the generation of heat and abstraction of water that accompany slaking which give rise to the popular idea that quick lime produces a caustic or burning effect. As a matter of fact, after slaking has taken place and the normal temperature is reached, the resulting hydroxide is very mild in its action on organic material.

In light sandy soils which contain little organic matter, the amount or carbonic-acid gas in the soil water is apt to be small, and the water-holding power of such soil is low. If slaked lime be added to such a soil (there being little opportunity for chemical combination) much of the lime would be lost by leaching.

LIME OXIDE COMPARED WITH LIME CARBONATE

All forms of oxide of lime when slaked are extremely fine, so that their value depends on their purity or content of lime oxide.

The farmer has, then, in the choice of material, the following facts to consider regarding the efficiency of lime in the soil: All forms of ground or pulverized carbonate of lime are approximately alike if their purity is the same and they have the same degree of fineness. It is evident then, for immediate effect, that the value of carbonate as compared with oxide depends on the equivalent value of carbonate when calculated to oxide, and how nearly its fineness approaches the fineness of slaked lime.

The relative value of lime carbonate and oxide of lime is in the ratio of 56 to 100; or, other words, 100 pounds of carbonate will produce 56 pounds of oxide on burning.

The finer limestone is ground the more it will cost and the more soluble and effective it will be in the soil. There is, however, a point where added expense for fine grinding is not warranted, because the increased crop production does not offset the increased cost of the material. Results from field tests regarding the efficiency of limestone of different degrees of fineness, though varying considerably as influenced by differences in soil, crop, and climate, all support the proposition that some fine material is necessary for immediate effect.

It may safely be assumed, therefore, that in the case of ground or pulverized limestone it is only the material of certain fineness that is immediately available and is comparable in value with the fine material obtained on slaking burned lime. Coarse material, though not quickly available, is of considerable value, as its slow solubility makes it a reserve store of lime in the soil.

Specifications regarding the fineness of grinding of limestone have varied considerably. A material of which a large percentage passes through a 60-mesh sieve probably comes near striking the medium between very fine material at very high cost and coarse material procured cheaply. However, when it is specified that all the material shall pass a 10-mesh sieve, there is usually enough fine material present to produce immediate effects. Cases have been known where limestone was ground so that all the material passed a 10-mesh sieve, and then the fine material was sifted out for other uses. Such pulverized limestone would, of course, be only slowly effective.

The following facts should be borne in mind in this connection: It requires approximately twice as much carbonate of lime to bring about the same chemical effect as oxide, or quicklime. It is necessary that a considerable part of ground or pulverized carbonate (limestone) be fine material to make it immediately effective. If, then, a brand of ground limestone contains a fairly large percentage of fine material and contains 85 per cent or more of carbonate, it is probably worth, for immediate effect, half as much per ton as a high grade of burned lime.

Comparative tests of burned lime and ground limestone have been made at many of the agricultural experiment stations on a variety of crops; and although in some cases burned lime has been found to give the greater yield and in other cases the ground limestone, the general opinion is in agreement with that expressed in a bulletin from the Ohio Experiment Station:

> In actual practice the experiments made by the Ohio Experiment Station have shown no practical superiority of one form of lime over the other provided the limestone has been so ground that 80 per cent of it will pass through a sieve having 100 meshes to the linear inch and provided, of course, that the two materials have been used on the basis of the actual calcium contained.

It would be possible to prepare a table comparing the relative values in oxide of lime content of limestone varying in calcium carbonate content from 70 to 95 per cent. Then assuming that only that portion passing a sieve of some arbitrarily selected dimensions—say 60 meshes to the inch—was available, enlarge the table to show the relative values of the various grades when ground so that 20, 40, 60 or more per cent passed such a sieve.

In view, however, of the absence of definite data on the availability of limestone of different degrees of fineness such a table might not only be misinterpreted but misused.

Availability as applied to limestone means the ability to become soluble and to become part of the soil solution to react with the soil or feed the plant. As a matter of fact availability does not depend on the condition of the limestone alone. The nature of the soil, rainfall, and temperature are all factors.

This consideration emphasizes the desirability for the farmer of experimenting on a small scale with liming material until he determines what kind and condition of material is best suited to his needs.

Hydrated lime carries with it the water that has combined with the oxide, and consequently its oxide value for equal weight is less than that of quicklime. The relation between the two is such that 100 pounds of hydrated lime contains approximately 75 pounds of oxide, and the relation between the three is as follows: 100 pounds

of carbonate (limestone) is equal to 74 pounds of hydrate (slaked lime) or 56 pounds of oxide (burned lime); or, to put it in general terms, 2 parts of oxide are equal to 3 of hydrate or 4 of carbonate.

In the past opinions differed considerably regarding the value of magnesian limestone or the lime made from it for agricultural purposes, but the general opinion now seems to be that they are equal in value to the limestone or lime from ordinary limestone if of the same purity and degree of fineness. The relation of magnesia carbonate to magnesia oxide is slightly different from that between lime carbonate and lime oxide, but the difference is so small that for all practical purposes the value of a magnesian limestone can be judged by its content of the two carbonates and lump lime by its content of the two oxides.

OTHER FORMS OF LIME

Other lime compounds than those discussed here are sometimes added to soils either directly or as components of fertilizers or other material.

Land plaster.—Land plaster, known also as gypsum, calcium sulphate, or sulphate of lime, has been somewhat extensively used in agriculture. This lime compound is not active in neutralizing soil acidity; and although it may bring about some of the other effects of liming, its action, which is frequently referred to as a stimulating one, may be chiefly that of liberating plant-food elements from soil minerals. Land plaster is also of value as an addition to manure and composts because it prevents the escape of ammonia from such materials.

Superphosphate (acid phosphate).—Superphosphate (acid phosphate) is prepared by treating rock phosphate with sulphuric acid, and it contains both acid phosphate of lime and sulphate of lime. Superphosphate is sometimes used alone as a fertilizer, but usually as an ingredient of mixed fertilizers. For every 1 per cent of phosphoric acid in such material there is approximately 2 per cent of sulphate of lime and one-third of 1 per cent oxide of lime combined with phosphoric acid. Some of the effects of superphosphate may be due to the calcium thus furnished; and although, theoretically, it has no power to neutralize acids it has been observed that its continued use tends to lower the acidity of acid soils.

Ashes.—The ashes that remain after burning wood contain some of the mineral elements that were in the wood, in the form of oxides or carbonates. Potassium carbonate and calcium carbonate or oxide are present in considerable and frequently large quantities, so that ashes have a strong alkaline reaction and have the power to neutralize acid. The commercial value of wood ashes usually depends more on their content of potash than of lime, but nearly all contain enough lime to warrant their being considered among liming materials. Even ashes that have been leached to recover potash contain enough lime to make them of value for liming purposes.

Compost and manure.—All vegetable and animal materials contain some calcium usually in combination with organic material or acids; and when it is added to soils, this lime goes to replenish the store of calcium in the soil. Lime from such sources is not effective in correcting soil acidity or improving the physical condition of a soil.

Basic slag.—Basic slag, known also as Thomas slag, is a by-product of the iron industry and is used as a fertilizer, but its present production and use is small. It is a phosphate of lime with an excess of lime. It has an alkaline reaction and when used on an acid soil tends to bring about a neutralization of acid conditions to the extent of the excess of lime in it. Usually, however, it is not used in sufficient quantity to bring this about to more than a very limited degree.

Cyanamid.—Calcium cyanamid is used as a fertilizer both alone and as an ingredient of mixed fertilizers. As a fertilizer it is used as a source of nitrogen. The nitrogen, however, is combined with lime, which may bring about some of the effects of liming. Cyanamid also usually contains free lime and is alkaline in reaction and to some extent may bring about correction of acidity.

OTHER FACTORS IN LIMING

TIME AND METHOD OF APPLICATION

To a large extent the time and method of application are fixed by the kind of material, the nature of the soil and crop, and the farmer's convenience. So far as any possible injury to the crop is concerned, carbonate of lime may be applied at any time. This material produces no injurious effect by direct contact with seeds or young plants and does not tend to set ammonia free from stable manure. It should, however, not be mixed with or applied at the same time as acid phosphate, since this tends to bring about a change of the water-soluble phosphorous compound to an insoluble form.

Oxide of lime either in the form of burned lime or hydrated lime requires somewhat more care in application. It should not, especially if it is unslaked, be applied so that it comes in contact with seeds or young plants. Like the carbonate, it should not be mixed with acid phosphate. Neither should it be mixed with stable manure, as this brings about loss of ammonia.

Lime may be applied by drilling with a seed drill or by spreading with a lime spreader. (See title page and fig. 1.) Drilling is not a satisfactory method if the lime is not in a proper condition to be uniformly distributed. Various types of lime spreaders are on the market, and it is often possible for the farmer to devise home-manufactured machines for this purpose that are satisfactory. A manure spreader can also be used for this purpose by putting a thin layer of manure in the bottom and gauging the load according to the quantity to be spread. The practice of placing burned lime in piles in the field and slaking it by the addition of water or allowing it to slake in the air and then spreading by hand is a somewhat common one. This is a very disagreeable operation, and uniform distribution is difficult to accomplish.

Whether lime should be applied before plowing or after plowing, as well as the time and manner of applying, are matters that must be decided in each case according to conditions. Probably, application after plowing, followed by harrowing, is the most general and satisfactory practice. The desirability of having the lime as thoroughly and uniformly distributed through the soil as possible should always be kept in mind.

QUANTITY

The quantity to be applied naturally depends on the needs of the soil, on the form of lime used, the crop, the climatic conditions, and the time of application. Applications of burned lime are usually from one-half a ton upward, or the equivalent, of carbonate of lime, although beneficial results frequently may be obtained by the use of smaller quantities. The conditions that make it necessary to lime tend to recur again, depending on the soil and its treatment. This makes it necessary to repeat the liming from time to time.

The question whether a large application once in several years is preferable to smaller applications more frequently is one regarding which no general rule can be made. Arguments can be presented in favor of each procedure, and it is a matter where experiment and experience must decide. The present tendency is toward lighter applications at more frequent intervals.

LOSS BY LEACHING

The leaching of lime from a soil, resulting in loss of valuable material, is a matter that should receive consideration in the practice of liming. It must be remembered that the finer a lime material is pulverized the more quickly it reacts in the soil; and if very fine material is applied in excess, it will be leached from the soil and lost.

This loss by leaching is a factor operating particularly in light soils which have little organic matter and in which the drainage is good or even excessive. It is especially important in the South, where such soils predominate and where the mild climate and heavy rainfall bring about leaching throughout the year.

GREEN MANURE

The practice of liming is very closely related to that of growing green crops to be plowed under to furnish organic material to the soil. Good results frequently follow the plowing under of green crops where no liming is practiced, but usually the benefit will be greater if lime is applied to the soil.

Few farms produce enough manure to maintain the organic content of all the land at the point where it should be. The use of commercial fertilizers which contain organic matter such as dried blood, tankage, or cottonseed meal, contribute but small quantities of this material. The plowing under of green crops is therefore the only other method of accomplishing this result. Leguminous crops such as clovers and cowpeas are usually grown for this purpose, although nonlegumes, such as rye, are sometimes used.

SOIL ACIDITY

Soil conditions that make liming desirable or necessary are in many cases matters of ordinary observation or experience, but the reasons for this are frequently but not always apparent. This is particularly the case with regard to the reaction of the soil, whether or not it is acid.

Though it may be assumed that a soil rich in organic matter is acid and that certain types of native vegetation indicate acid soils, the great majority of cultivated soils that may be slightly acid do not indicate that fact in any way that is conclusive to the farmer.

INDICATORS OF SOIL ACIDITY

Soils that contain large quantities of organic matter, such as peat or muck, if not intimately associated with marl deposits, are usually acid. Soil acidity is frequently associated with poor drainage.

The character of the native vegetation often indicates an acid soil. Among such indicators may be mentioned the growth of blueberry and wintergreen bushes, the presence of chestnut and sassafras trees, or a scrubby growth of oak or jack pine. In cultivated fields the presence of weeds such as sorrel or growth of moss on the surface may indicate acidity, but generally in cultivated soils that may be slightly acid some test must be applied to the soil.

THE LITMUS-PAPER TEST

Certain dyes change color in the presence of acids or alkalies. Such dyes when used to test for acids or alkalies are known as indicators, and litmus is one commonly used in this way. When in contact with moisture and an alkali such as lime hydroxide litmus turns blue; and if to the blue litmus a slight excess of acid be added, it turns red.

Litmus paper is an absorbent paper saturated with red or blue litmus, and this when properly prepared is sensitive to slight acidity or alkalinity. Litmus paper is used in testing soils for acidity; and the test usually is made by moistening the soil to form a compact mud, making an opening in this, inserting a strip of blue litmus paper, closing the soil around it and allowing it to stand for a short time and then noting any change of color. Precaution should be taken to prevent contact of the moist litmus paper with the fingers, and not to mistake a staining of the paper with the grains of red soil for a change of color of the paper.

The interpretation of the change of color, if such occurs, is a matter of personal judgment, and is most reliable when used by some one who has had experience. In any case, the litmus-paper test ordinarily can do no more than indicate whether the soil is slightly or strongly acid, and it does not tell the quantity of lime that may be necessary to correct the acidity. A great many soils that do not show a strongly acid reaction with litmus paper require an application of a considerable quantity of lime before they will show an alkaline reaction with red litmus paper.

THE TRUOG TEST

A test for soil acidity that has come into somewhat general use for field work is known as the Truog test. This depends on the fact that if an acid is brought into contact with zinc sulphide a disagreeable-smelling gas known as hydrogen sulphide is given off, and even traces of this can be detected by the darkening of white paper mois-

tened with a solution of lead acetate (sugar of lead). The dark stain is lead sulphide.

This test, though rather simple and easily carried out, requires some apparatus and chemicals and is best made by some one familiar with such equipment, such as the county agent or some representative of the State experiment station. On many soils this test gives more conclusive evidence of acidity than does litmus paper and also gives more definite information regarding the degree of acidity. However, should the soil require lime for some other reason than acidity, this test will of course not indicate it. Several other methods for determining soil acidity or lime requirement have been proposed and used by different soil investigators. Among these may be mentioned the Hopkins and Jones methods.

LIME REQUIREMENT

The term "lime requirement" is frequently used in discussing liming of soils, and it usually means the quantity of lime that must be added to a soil to bring about a slight alkaline reaction. Such lime requirement includes not only the lime necessary to neutralize any acid present but also that which may be used up by the soil in other ways such as absorption by the very finely divided soil material (colloids) or by chemical reaction with soil minerals. This lime requirement is usually stated in pounds of lime per acre to a stated depth. A method by which this lime requirement is usually determined is known as the Veitch method. It requires laboratory equipment and is not adapted for field use.

LOCAL GRINDING OR BURNING

If deposits of limestone are found on or near the farms on which it is desired to practice liming, grinding or burning such material with farm labor and equipment is often desirable and practicable. The chief items of cost of ground or burned lime prepared on the farm are labor, the operation and depreciation of machinery or equipment, and fuel, and the chief advantage in utilizing such a deposit is in the saving of freight and haulage and the ability to obtain material when wanted.

It may be taken for granted that any farmer or community of farmers in attempting to use a local limestone supply may not turn out a product as efficiently as will a manufacturer with larger equipment and experience in the business, so that the project should receive careful consideration before being undertaken.

Furthermore, prospective purchasers of portable crushers should not be satisfied with a demonstration unless assured that the limestone with which the demonstration was made is as hard as that they propose to grind.

It is not likely that local lime burning can be profitably conducted by farmers except where a local supply of cheap fuel is available. In the case of both local grinding and burning limestone of lower grade can be made use of than could be used for the commercial production of liming material.

In the utilization of local limestone or marl no expense should be incurred for machinery or equipment without first having the ma-

terial it is proposed to use analyzed or examined by one competent to judge of its value for agricultural purposes.

STORAGE OF LIMING MATERIAL

Where lime is to be used extensively, especially where a number of farmers are interested, some means of storage of the lime material

FIG. 5.—A community lime storage bin

is very desirable. Storage bins located on a railroad siding make it possible to have a supply of lime on hand that can be hauled and distributed at the farmers' convenience. Such bins may be of various types but should provide for convenient unloading from cars into them and easy loading into wagons or trucks. (Figs. 5 and 6.) For the satisfactory operation of such storage facilities a scale for weighing loads hauled away is very desirable.

WHAT SHOULD NOT BE EXPECTED OF LIMING

Liming will not take the place of drainage. Acid-soil conditions may be due to poor drainage, but lime can improve only the conditions in the upper soil, making for better circulation of air and water. Impervious layers of hardpan are not materially affected by applications of lime but should be broken up by other means.

Liming can not take the place of proper crop rotation, cultivation, or soil management. In fact, the use of lime makes it more necessary that rotation and all cultural methods be studied more carefully.

Lime does not supply any of the constituent elements furnished by fertilizers—potash, phosphoric acid, or ammonia.

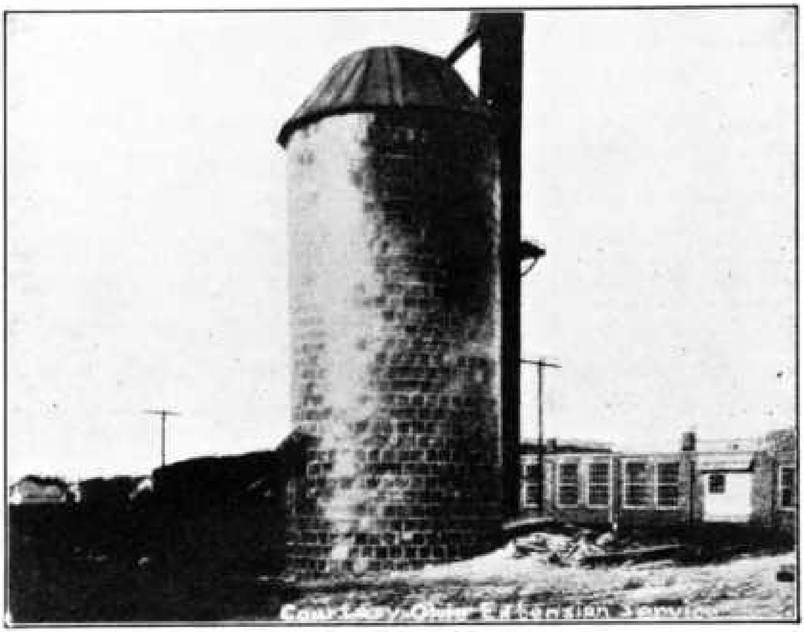

FIG. 6.—Lime storage bin with elevator

Best results should not be expected from an application of lime on soil deficient in organic matter, and liming should not be expected to build up such a soil unless such organic matter is supplied either in manure or green crops plowed in. On soils deficient in organic matter it is often necessary to lime first in order to build up organic matter by means of green-manuring crops.

TERMS USED IN LIMING

The following terms are used commonly in discussing the agricultural use of lime. The majority of these have appeared and have been defined in the foregoing text, but for convenience are repeated here.

Weight of lime.—A Federal statute provides that in interstate shipment a large barrel of lime shall consist of 280 pounds, and a small barrel, 180 pounds net

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weight. The weight of a bushel of lime is fixed by law in several States and varies from 72 to 80 pounds.

Reaction.—The term "reaction" is applied to the behavior of a solution or a solid, when moist, when brought in contact with certain dyes called indicators. A solution or solid (when moist) that turns blue litmus red is said to have an acid reaction and one that turns red litmus blue an alkaline reaction. Slaked lime or lime hydroxide has an alkaline reaction.

Lime requirement.—The lime requirement is the quantity of lime it is necessary to add to a soil to produce a slight alkaline reaction. It is usually stated in pounds of lime per acre to the depth of 6 inches or more.

Fat or rich lime.—Fat or rich lime is sometimes called hot lime. It is made from limestone which contains less than 10 per cent of impurities. On slaking it usually generates considerable heat.

Lean or poor lime.—Lean or poor lime is made from limestone which contains more than 10 per cent of impurities. It usually slakes slowly. Limestones ground for agricultural use frequently yield poor or lean lime on burning. The terms in this and the immediately preceding paragraph are used commonly in the building trade.

Magnesian or dolomitic lime.—Magnesian or dolomitic lime is made from a limestone which contains from 10 to 15 per cent or more of magnesium carbonate.

Hydrated lime.—Hydrated lime is a trade name for slaked lime or lime hydroxide, prepared by manufacture.

Carbonate of lime.—Carbonate of lime is a compound consisting of lime oxide combined with carbonic-acid gas. It occurs naturally as limestone, marl, oyster shell, and coral.

Oxide of lime.—Oxide of lime, or quicklime, is formed from carbonate by burning, whereby the carbonic acid is driven off. It does not occur in nature. It is known in trade as burned lime, lump lime, quicklime, stone lime, caustic lime, or builder's lime.

Hydroxide of lime.—Hydroxide of lime is a combination of oxide of lime with water. It is also known as slaked lime and hydrated lime.

Agricultural lime.—The term "agricultural lime" was originally applied to burned lime prepared for agricultural use, but now the term is somewhat commonly applied to any form of lime intended for use in soil improvement.

Liming.—Liming is the application of lime either in the form of carbonate or oxide to the soil.

Lime-oxide equivalent.—The lime-oxide equivalent is the proportion of oxide of lime in a carbonate or hydroxide. In pure material the ratio is approximately 2 parts of oxide (burned lime) to 3 parts of hydroxide (slaked lime) or 4 parts of carbonate.

Sieves.—In grading ground or pulverized limestone or similar products sieves of different-sized mesh or openings are used to separate the material into proportions of different grades of fineness. A 10-mesh sieve has 10 meshes to the running inch, or 100 meshes per square inch. A 60-mesh sieve has 3,600 meshes to the square inch.

Organic matter.—Organic matter is animal or vegetable material that has been left in or added to a soil. It includes material in all stages of decomposition from comparatively fresh material, the origin of which can be determined, to that in an advanced state of decomposition and in part, at least, combined with the mineral constituents of the soil.

Humus.—The term "humus" is applied to the more or less dark-colored, thoroughly decomposed organic material in a soil. It is known to be made up of a great variety of organic compounds.

Green manure.—"Green manure" is a term applied to any crop grown for the purpose of being plowed under to replenish the supply of soil organic matter. Leguminous crops, such as the clovers and cowpeas, are grown most frequently for this purpose, but others, such as rye, are sometimes used.

Hydrogen-ion concentration.—The term "hydrogen-ion concentration" is frequently used in discussing the intensity of the acidity of a soil at some particular time. This concentration is measured in the laboratory by special electrical equipment and can also be measured by the use of indicators, either in the field or laboratory.

While these measurements give an accurate determination of the intensity of the acidity they are of little practical value in determining the quantity of lime required in agricultural practice.

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